PILOT STUDY AND EVALUATION OF A SMMR-DERIVED SEA ICE DATA BASE

Final Report
to
National Aeronautics and Space Administration
(Goddard Space Flight Center)

NAGW-363

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1. Introduction

Researchers in the geophysical sciences currently have problems utilizing large volume satellite data sets because of the difficulties in obtaining, processing and applying the data. This study proposed to evaluate the Nimbus-7 Scanning Multichannel Microwave Radiometer (SMMR) data and to document the type of problem users have with satellite data. The main objectives were:

1. To produce products (summary graphics and monthly/seasonal averages) useful to the snow and ice community from the Nimbus-7 SMMR data product sets, specifically the orbital PARM-SS and gridded MAP-SS data sets for 1979.

2. To provide input to NASA-Goddard about difficulties experienced in using the data products and suggestions for improvements to them.

3. To verify selected snow and ice information in the SMMR data set with "ground truth" data from other independent sources within the Data Center.

The major tasks have been completed. However, areal ice statistics were not produced, because spurious regions of sea ice concentration and multiyear ice fraction were identified on the data tapes. The data would have to be reprocessed in order to obtain meaningful statistics and this was not within the scope of this project. Most of the work has been concerned with sea ice parameters, although snow parameters could also be obtained and displayed with all of the software products that have been developed.

2. Product Development

Prior to producing specific data products, a user survey of scientists interested in sea ice data was carried out.

2.1 User survey

A questionnaire for potential SMMR data users was developed and distributed to the sea ice community to survey the type of media and products desired by scientists. A preliminary evaluation of the questionnaire was obtained by distributing it to participants at the Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave Imager (SSM/I) Working Group meeting 14-15 December 1982 at Seattle, Washington. A revised version based on comments from the Working Group and NASA-Goddard scientists was completed and then distributed to the sea ice community in January 1983. The survey showed that the sea ice community's interests are primarily in microwave-derived sea ice concentration and multiyear ice fraction. Preferences were also expressed for producing data at the highest spatial and temporal resolution available. Detailed results are given in Appendix A.

2.2 Software development

Sample SMMR data tapes for the PARM-SS and MAP-SS and their respective documentation (PARM-SS tape specification no. T23413 and MAP-SS tape specification no. T23411) were obtained from NASA-Goddard in August 1982. Initial software development for accessing the data using the Environmental Data and Information Services (EDIS) Univac computer system was conducted for the sample tapes. During this development, it was discovered through hand conversions of the binary data that discrepancies existed within the tape specification documentations (see section 3.1). Because of these and other possible discrepancies, printed output produced by NASA-Goddard for the first record of the sample PARM-SS tape was obtained so that visual comparisons could be made with our generated output. This proved to be an important step in verifying our software development.

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Using the results from the questionnaire, software was developed which would retrieve data from the PARM-SS tapes on a given parameter for a specified region and time period. Extraction of a complete grid for a single parameter from the MAP-SS tapes was also made possible. The extracted digital data can also be displayed as a graphical product. Examples are attached in Appendix B. They include hemispheric scale maps of sea ice concentration and multiyear ice fraction obtained from the MAP-SS data tapes and regional scale maps derived from the PARM-SS data. These maps were produced with a Hewlett-Packard plotter on the NOAA/NESDIS/NGDC Data General Eclipse computer using the NCAR graphics package.

3. User Difficulties

3.1 Documentation

During the development of the computer software, discrepancies were found in the two tape specification documentations. These problems included:

- the incorrect information in the bit tables; the most serious is the reversal of latitude and longitude bytes, 1309-1312 with spare bytes 1313-1316 on the PARM-SS bit table.

-parameter numbers listed in the documentation on both the PARM-SS and MAP-SS tape specifications did not match the numbers obtained from the tapes.

- scaling coefficients did not match the documentation for sea ice concentration on the MAP-SS tapes. For example, 90% concentration are coded on the tapes as 90, whereas the documentation required the data to be in the form 900.

- the wrong identifier codes for the type of map projection (eg. northern polar stereographic) were listed in the documentation for MAP-SS tapes.

These discrepancies and others were communicated to NASA-Goddard (via P. Hwang) and most have been corrected. Some of these problems created major delays in our software development to unpack the data.

The tape specifications are also incomplete in their description of the various indices available in the data. For example, the quality flags listed in the bit tables for the PARM-SS tapes are not explained in the documentation. The flags were reported not to have been used and their locations should be taken as spares. Even in the most recent documentation, however, they are still listed as quality flags in the bit table.

Further documentation could be added to the MAP-SS specifications explaining the monthly maps. This could include information that the monthly maps are available only for the film specification numbers F231702 and F231704 and include only parameters listed under those numbers. It would also be helpful to know that the monthly maps are given in the last two frames of each of the MAP-SS tapes.

The first year of data and tape specifications were ordered from the National Space Science Data Center (NSSDC) in May 1983. The tape specifications sent were outdated when compared to the documentation received with the sample tapes in August 1982. This information was again reported to NASA-Goddard (via P. Hwang). The second year of data was received in late April 1984 and the specifications (User's Guide for the Nimbus-7 Scanning Multichannel Microwave Radiometer(SMMR) PARM and MAP Tapes) were the most up to date version so that the majority of the errors found on the earlier documents had been corrected. The latest documentation received in June 1984 has incorporated further revisions, but errors still exist in the document. They include:

- the mislabeling of the PARM-SS bit table with the title from the PARM-L/O bit table.

- the wrong number of bits (976) for the data distribution given in the

tape description compared to the correct value (96) given in the MAP-SS bit table.

- the incorrect definition of the MAP products' data coverage. In the introduction, the documentation states that only 6 day and monthly maps exist, however, there are also 3 day maps available which are explained in the appendix on MAP tape formats.

- the absence of a statment that the gridded sea ice concentrations are derived from the 37 GHz channel for year one and the 18 GHz channel for year two.

These are being reported to NASA-Goddard (via P. Hwang).

During the verification of the SMMR data more problems in the documentation were discovered. These included:

- the wrong equation given to calculate the physical temperature of the ice (T_{ice}).

- the lack of documentation to explain the spurious regions of large sea ice concentrations caused by ocean and precipitation effects.

- no documentation to enable the conversion of the gridded MAP-SS data back to latitude and longitude coordinates. This information is extremely important when applying the data for regional analysis of a parameter.

- a clear definition of multiyear ice, since the WMO definition differs.

These problems were also communicated to NASA-Goddard, but the majority of these have not been addressed in the revised editions.

The current documentation could also be reorganized. A section on the description of the PARM data should be added before the description of the MAP data. The geophysical parameter quality section could precede the description of the data sets. In the appendices, the data tape header information should probably be the last appendix and the parameter tables for both PARM and MAP

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should be repeated in the appropriate appendix. To help the understanding of the documentation and data formats, we recommend that a sample data set in both digitial and hardcopy be included when a user requests the data so that verification can be made with their software.

In general it was found that the original documentation which accompanied the PARM-SS and MAP-SS data tapes were incomplete and contained erroneous information. Another user of the MAP-SS data had a similar reaction to the documentation, observing that it contained several errors and was hard to understand (R. Moritz, pers. comm.).

3.2 Data set

In the attempt to verify and apply the PARM-SS and MAP-SS data many difficulties arose within the data set. These difficulties included both the format in which the data were archived and the actual data. It was observed that the PARM-SS data tapes contained data for the complete orbit, encompassing tropical regions. These non-cryospheric data areas contained only missing values. This seems to be a waste of space and causes extra computer time to skip these regions.

In the MAP-SS data the resolutions of sea ice concentration and multiyear ice fraction do not coincide. The sea ice concentrations are archived in a 355 x 355 grid. This represents a grid spaceing of approximately 30 km resolution to 50° N. The multiyear ice fraction is stored in a 267 x 267 grid with a 60 km resolution to 30° N. Our conversions of the 60 km resolution data to 50° N produce a grid which is 213 x 213. This is, however, not half of the 355 x 355 grid. This becomes important when one desires to calculate multiyear ice concentrations from the gridded sea ice concentrations and multiyear ice fraction to produce area statistics for multiyear ice. It should be noted,

however, that the PARM-SS data for both sea ice concentration and multiyear ice fraction are archived at the same 60 km resolution.

The actual data archived might create problems for data users. The sea ice concentrations stored on the MAP-SS tapes for the first year were calculated using the 37 GHz channels while the second year uses the 18 GHz channels. The change is not currently mentioned in any of the documentation. The PARM-SS sea ice concentrations were calculated from the 18 GHz frequency for both years. The 37 GHz frequency is more sensitive to ocean effects and this can be seen in the spurious areas of large concentrations, as high as 80-90 percent, found well to the south of the ice limit in the Pacific and Atlantic Oceans (Anderson et al., 1984). Rainfall will also contribute to spurious concentrations. Future SMMR data will use a spectral gradient ratio filter to remove these spurious regions. This will not be the case for the first three years of data produced unless the products are reprocessed. Spurious multiyear ice fractions are also observed in regions where only first year ice is expected. These regions are discussed further in section 4.

It should be noted that, the recent publication by Gloersen et al. (1984) introducing the Nimbus-7 SMMR CELL, PARM and MAP data does not directly use the data which are available from the NSSDC. This paper uses results from Cavalieri et al. (1984), who formulate their own gridded data set for sea ice concentrations from the 18 GHz channel. The MAP-SS data are derived from the 37 GHz channel. The 18 GHz derived sea ice concentration has errors of approximately 16% in open oceans (Cavalieri et al., 1984) while the MAP-SS data has errors as high as 80% (Anderson et al., 1984). These larger errors will not occur in the second year (1980) data because of a change from the 37 GHz to 18 GHz channel for the MAP-SS sea ice concentrations. The PARM-SS could also be gridded by the user to obtain the same results as Cavalieri et al. (1984), but the purpose of the gridded products was to allow the user not to have to process

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the orbital data into a gridded format. This publication may inadvertently misinform the potential user of the NSSDC data.

4. Verification

Two case studies were conducted to verify the SMMR derived sea ice concentrations and multiyear ice fractions with other data sets available at the World Data Center - A for Glaciology (Snow and Ice). The first case study investigated a lobe of ice displaced from the the pack on the eastern side of Greenland, referred to as the "Odden" (Vinje, 1980). The lobe of ice appears in January 1979 and persisted through the early part of May 1979. DMSP visual imagery was used to verify the existence of the ice position and concentrations reported on the PARM-SS tapes. There was good agreement with the imagery except that the SMMR data had concentrations around 20% were no ice was observed on the imagery. These differences were probably caused by ocean effects. The second case concerned the breakup of sea ice in the Sea of Okhotsk during May 1979. Visual DMSP imagery as well as Japanense Meteorological Agency sea ice charts were used to verify the position and concentrations of ice. Again, the SMMR data had a good correspondence with the imagery and sea ice charts. A detailed study of these ice decay events during May is given by Anderson and Crane (1984).

Spurious regions of multiyear ice fraction were also observed in the MAP-SS data. Further investigation was conducted for May 1979 in the Kara and Barent Seas where temporary appearances of high multiyear ice fraction occurred in early summer. This included the examination of the 18 and 37 GHz vertical brightness temperatures, visual DMSP imagery, and the Norwegian sea ice charts. The results are described by Anderson et al. (1984). It is suggested that the occurrence of these spurious areas of multiyear ice fraction may yield

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additional information on the incipient melt phase, although the precise physical effects that are occurring have not yet been determined.

5. Summary

Significant information has been gathered on the project objectives. The user survey has supplied information on the type of media and products desired by the sea ice community and this knowledge was implemented into our products. Our software development has also provided information for NASA-Goddard concerning discrepancies in the tape documentation, most of which have been corrected in later editions. The verification and application of the SMMR PARM-SS and MAP-SS data in case studies have also provided information about the data set to NASA. Some of this input has been applied to the planning of future satellite microwave data bases, for example, the DMSP SSM/I sensor data which will be processed and archived at World Data Center-A for Glaciology following a test phase in 1986.

6. References

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Appendix A.

Results of the World Data Center-A Glaciology [Snow and Ice]
Questionnaire on the Scanning Multichannel Microwave Radiometer

RESULTS OF THE WORLD DATA CENTER-A FOR GLACIOLOGY [SNOW AND ICE]
QUESTIONNAIRE ON THE SCANNING MULTICHANNEL MICROWAVE RADIOMETER

April 1983

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Introduction

The World Data Center-A for Glaciology has conducted a survey of potential users of Scanning Multichannel Microwave Radiometer (SMMR) data for sea ice observations in order to provide NASA with an evaluation of user needs for SMMR data products. The results of this survey will help determine the best formats for the eventual distribution of specialized products useful to sea ice research and operational programs.

Methodology

To conduct the survey an informational sheet about the NASA produced SMMR data sets and a short questionnaire were developed and distributed to the sea ice community (copies in Appendix A). This brief description of the SMMR data sets was designed to enable an individual who was not familiar with the data set to answer the questionniare. The questionnaire was constructed in a manner which would lead to quick and easy response, in hope of receiving maximum replies.

The description and questionnaire were then distributed at the Special Sensor Microwave Imager (SSMI) Working Group meeting, 14-15 December 1982, at Seattle, Washington, as a test evaluation. Comments from the Working Group participants and NASA-Goddard scientists helped formulate the final version.

The revised survey was then distributed to 72 members of the sea ice community in mid-January 1983. These individuals were from both the academic and private sectors, as well as the foreign sector (list in Appendix B). Follow-up phone calls were made, where possible, when responses had not been received after 30 days.

Dr. R. Thomas of NASA Headquarters requested further polling of individuals who showed interest in brightness temperatures on the SMMR questionnaire. Information was needed concerning development of a new brightness temperature data set consisting of .5 by .5 degree latitude/longitude grids. The archived data

could be either averaged or time tagged, over periods ranging in length from one
to seven days. Currently the brightness temperatures are saved in orbital
format. The telephone responses to these questions are listed in Appendix C.

Results

59 out of 72 questionnaires were returned; a response rate of 82 percent. Of
those responding, 81 percent expressed interest in the SMMR data; the remainder
showed no interest in present or future usage of the data set.

With regard to the current SMMR products, the results (Table 1) show a strong
interest in the following: sea ice concentration, 89 percent; multiyear ice
fraction, 77 percent; and sea surface temperature, 69 percent. There was also a
greater interest in receiving sea ice concentration at 30 km resolution rather
than 60 km resolution.

The response to the temporal coverage question (see Table 1) indicates the
need for data formatted as either orbital data for 6 calendar days (which is 3
data days). 70 percent preferred the data in one of these two formats.

The results of the spatial coverage question were not as conclusive. There
were no strong differences between the three spatial domains (see Table 1):
regional coverage, 25 percent, global coverage, 21 percent, followed by a
hemispheric coverage, 15 percent.

Regarding the type of product (data medium) that would best fill the user's
needs, 54 percent of those responding prefer the current digital/computer
compatible tape format of packed binary data while 19 percent consider that a
tailored format would better satisfy their needs, 8 percent were undecided.
Concerning analog products, 50 percent responded that a map
format would suffice, over tabular or graphical forms. The idea of a statistical
product interested 29 percent.

Table 1

SMMR Questionnaire Responses

The following are the positive responses percentages

2. Would you be interested in:

    A. Antenna temperatures (TAT)   27%

    B. Calibrated brightness temperatures (CELL-ALL)   58%

    C. Derived products (PARM and MAP TAPES)

        1) Sea Ice Parameters:

a. sea ice concentration			89%
30 km resolution		42%	
60 km resolution		17%	
both 30 and 60 km resolution		31%	

            b. sea ice surface temperatures (156 km resolution)   69%

            c. multiyear ice fraction (60 km resolution)   77%

            d. 18 GH_z percent polarization (60 km resolution)   29%

        2) Land/sea parameters   31%

        3) Ice sheet parameters   35%

        4) Snow parameters   46%

        5) Ocean parameters   40%

3. What temporal coverage would be preferred?*

6 calendar days, 3 data days	27%
orbital data (1 day)	23%
orbital and 6 calendar days	20%
orbital, 6 calendar days and monthly	10%
monthly	8%
6 calendar days and monthly	8%
orbital and monthly	2%
	100%

4. What spatial coverage would be preferred?*

regional	25%
global (6 caladar days)	21%
hemispheric	15%
global, regional and hemispheric	15%
regional and hemispheric	12%
global and regional	10%
global and hemispheric	2%
	100%

5. What type of product would you use?

   A. Digital/computer compatible tape:

current format (packed binary data)	54%
tailored format to your needs	19%
no response	19%
undecided	8%
	100%

   B. Analog:*

maps	50%
graphical and maps	8%
tabular, graphical and maps	8%
tabular and maps	6%
tabular	2%
graphical	2%
tabular and graphical	2%
no response	23%

   C. Statistical (i.e. means, deviations, extremes, etc)   29%

6. Would you want SMMR data intergrated with other data sets (i.e.,
   meteorological data, pressure or temperature, etc.)?

   yes 61%   no 31%   no response 8%

   If yes, what type of data would you want integrated?

surface temperature	59%
surface pressure	52%
wind	31%
sea surface temperatures	17%
cloud cover	14%
buoy data	10%
meteorological data	10%
humidity	7%
sea ice data	7%
snow cover	7%
850 mb temperature	3%
850 mb pressure	3%
humidity profiles	3%
liquid precipitation	3%
ocean waves data	3%
1000-700 mb heights	3%
satellite and airplane data	3%
temperature profiles	3%

*The results were presented for all possible combinations
because some of the responses had more than one answer.

When questioned about integrating the SMMR data with other data sets, 61 percent showed an interest; of these, the different types of data that they would choose to integrate are shown in Table 1. The top five parameters requested are: air temperature, 59 percent; surface pressure, 52 percent; wind speed or direction, 31 percent; sea surface temperature, 17 percent; and cloud cover, 14 percent.

Conclusion

The reponses to the survey show a strong interest in the SMMR products from the sea ice community. Those potential users show the greatest interest in sea ice concentration, multiyear ice fraction, and sea ice temperature. Responses show that data should be provided at the best possible resolution for orbital or 6 calendar day periods at regional or global coverage. The majority would use the data in its current digital/computer compatible tape format or in a map form. The responses also show a desire to integrate the SMMR data with other data sets.

Appendix A

BRIEF DESCRIPTION OF SMMR DATA SETS

Sensor Description

The Scanning Multichannel Microwave Radiometer (SMMR) is one of several sensor packages on Nimbus 7. This satellite was launched 23 October 1978 and is currently operational. The SMMR package consists of a ten channel (five frequencies, horizontal and vertical polarizations per frequency) microwave radiometer producing polarized antenna temperatures at 6.6, 10.69, 18.0, 21.0, and 37.0 GHz.

The SMMR is activated on alternate days due to spacecraft power limitations. Therefore, one global coverage cycle is completed approximately every six calendar days. In addition, only areas between 85 degrees north and 85 degrees south latitude are observed due to spacecraft orbital inclination.

Data Formats

SMMR data will be available in 1983 in digital magnetic tapes and hardcopy map products. Both will be distributed through the National Space Satellite Data Center NASA. The current digital data include:

1)   TAT - raw antenna temperatures with polarization and geographic locations for each instantaneous field of view (IFOV) in orbital swath format. Ephemeris, spacecraft attitude, and SMMR housekeeping information are included.

2)   CELL-ALL - horizontal and vertical polarization brightness temperatures and seasonal geographic filters mapped in different size cells: 156, 97.5, 60, 30 km, according to frequency (smaller the frequency the larger the coverage), forming 780 km X 780 km blocks of data. Blocks are in orbital format.

3)   PARM TAPES - parameters for each IFOV derieved from geophysical algorithms in orbital format according to 2. The PARM TAPES are:

PARM-LO - land-ocean parameters
PARM-SS - sea ice and snow and ice on land parameters
PARM-30 - sea ice concentration (30 km resolution only)

4)   MAP TAPES - same parameters as the PARM TAPES but in digital format of map projections, mercator or polar, produced in six calendar day and monthly formats. The MAP TAPES are:

MAP-LO - mercator projection
MAP-SS - polar projection
MAP-30 - polar projection

The map hardcopy products include color annotated slides of mercator or polar projections containing geophysical parameters for either six calendar day or monthly periods to serve as a quick look or data catalog.

For further information about the SMMR sensor package please consult the Nimbus 7 User's Guide, NASA Publication, August 1978.

SMMR Questionnaire

Some questions may have more than one response. When appropriate, please rank your answers (1 = highest, etc.). If there is not sufficient room for comment, please attach a separate sheet.

1. General Information:

   A. Respondent

      Name _____

      Affiliation _____

      Address _____

      _____

      Phone (commercial) _____ FTS (if available) _____

      Project Director (if different from above)

      Name _____

      Address _____

      _____

      Phone (commercial) _____ FTS (if available) _____

   B. Are you now, or might you in the future, be interested in the SMMR products?

      Yes _____   No _____

                    IF YES, PLEASE CONTINUE

                                                    Please check
                                                    relevent box

2. Would you be interested in:

   A. Antenna temperatures (TAT)   ☐

   B. Calibrated brightness temperatures (CELL-ALL)   ☐

   C. Derived products (PARM and MAP TAPES)

      1) Sea Ice Parameters:

         a. sea ice concentration ☐ 30 km resolution ☐ 60 km resolution

         b. sea ice surface temperature (156 km resolution)   ☐

         c. multiyear ice fraction (60 km resolution)   ☐

         d. 18 GH_z percent polarization (60 km resolution) ☐

      2) Land/sea parameters   ☐

      3) Ice sheet parameters   ☐

      4) Snow parameters   ☐

      5) Ocean parameters   ☐

3. What temporal coverage would be preferred?

orbital data (1 day)   ☐   monthly   ☐

6 calendar days, 3 data days (approx. global coverage)   ☐

Other (explain)_____

_____

4. What spatial coverage would be preferred?

global*   ☐   hemispheric*   ☐

*(requires 6 calendar days or longer for complete coverage)

regional   ☐   other (explain)_____

_____

5. What type of product would you use?

A. Digital/computer compatible tape:

1) current format (packed binary data)   ☐

2) tailored format to your specific needs   ☐

B. Analog:

1) tabular   ☐   2) graphical   ☐   3) maps   ☐

C. Statistical (i.e., means, deviations, extremes, etc.)   ☐

6. Would you want SMMR data integrated with other data sets (i.e., meteorological data, pressure or temperature, etc.)?   Yes _____   No _____

If yes, what type of data would you want integrated?

_____

_____

7. List your possible applications of SMMR data:

_____

_____

8. Could you recommend others who might be interested in SMMR data (not on mailing list)?

Name _____

Affiliation _____

Address _____

Phone (commercial) _____ FTS (if available)_____

9. Other comments _____

_____

_____

_____

Appendix B

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Appendix C

.5 Degree Latitaude/Longitude Responses

A. Responses of individuals who showed interest in brightness
    temperature on the SMMR questionnaire.

    Preferred average data for one day but 4-7 days would be
    acceptable because of its global coverage.

    Preferred average data for the 4-7 day period.

    Preferred average data.

    Preferred average data for one day period.

    Preferred average data for one day period.

    Preferred time tagged data for the smallest time period
    possible, but averaged data was ok if for one day.

    Preferred averaged data for one day or time tagged for the
    4-7 day period.

    Preferred time tagged data for the 4-7 day period.

    Preferred time tagged data for the 4-7 day period.

    Average data were acceptable, but would like to know the
    number of observations in the square and/or the variance.

    Preferred the time tagged data for one day period.

    From his questionnaire, he would not be interested in a .5
    degree latitude/longitude data set.

B. Summary table.

	Time Period	
	1 day	4-7 days
Average data	4	3
Time-tested data	2	3

Appendix B.

SMMR Derived Sea Ice Concentration and Multiyear Ice Fraction Maps

NIMBUS 7 SMMR
SEA ICE
CONCENTRATION

PERCENT COVERAGE

20 ▼	◼	▲ 29
30 ▼	▦	▲ 39
40 ▼	▦	▲ 49
50 ▼	▦	▲ 59
60 ▼	▦	▲ 69
70 ▼	▦	▲ 79
80 ▼	▦	▲ 89
90 ▼	◼	▲ 94
95 ▼	▦	▲ 100
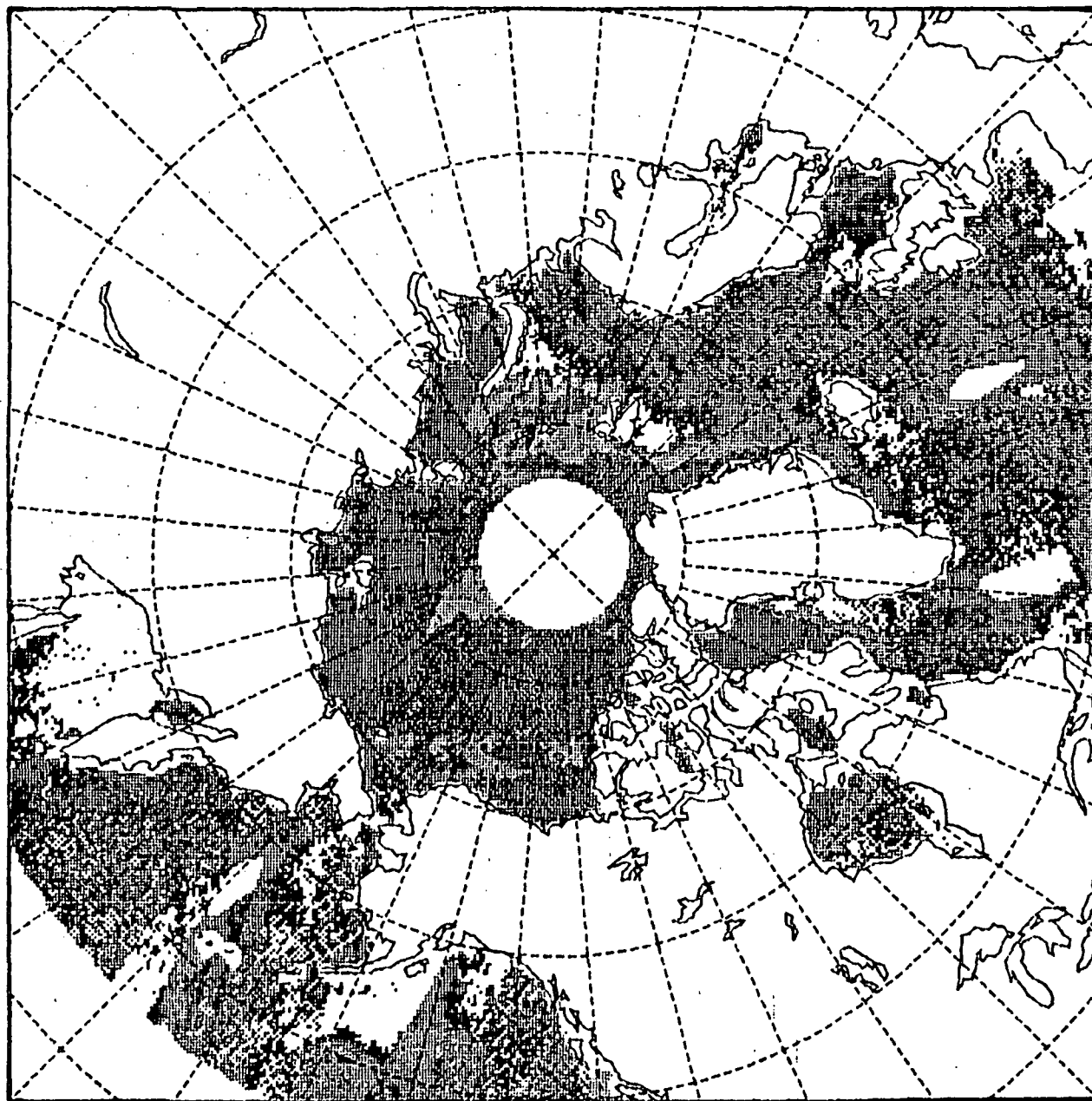
30 KM GRID

11 NOV 78 - 14 NOV 78

NIMBUS 7 SMMR
MULTIYEAR
ICE FRACTION

PERCENT COVERAGE

20 <	▨	> 29
30 <	▨	> 39
40 <	▨	> 49
50 <	▨	> 59
60 <	▨	> 69
70 <	▨	> 79
80 <	▨	> 89
90 <	▨	> 100
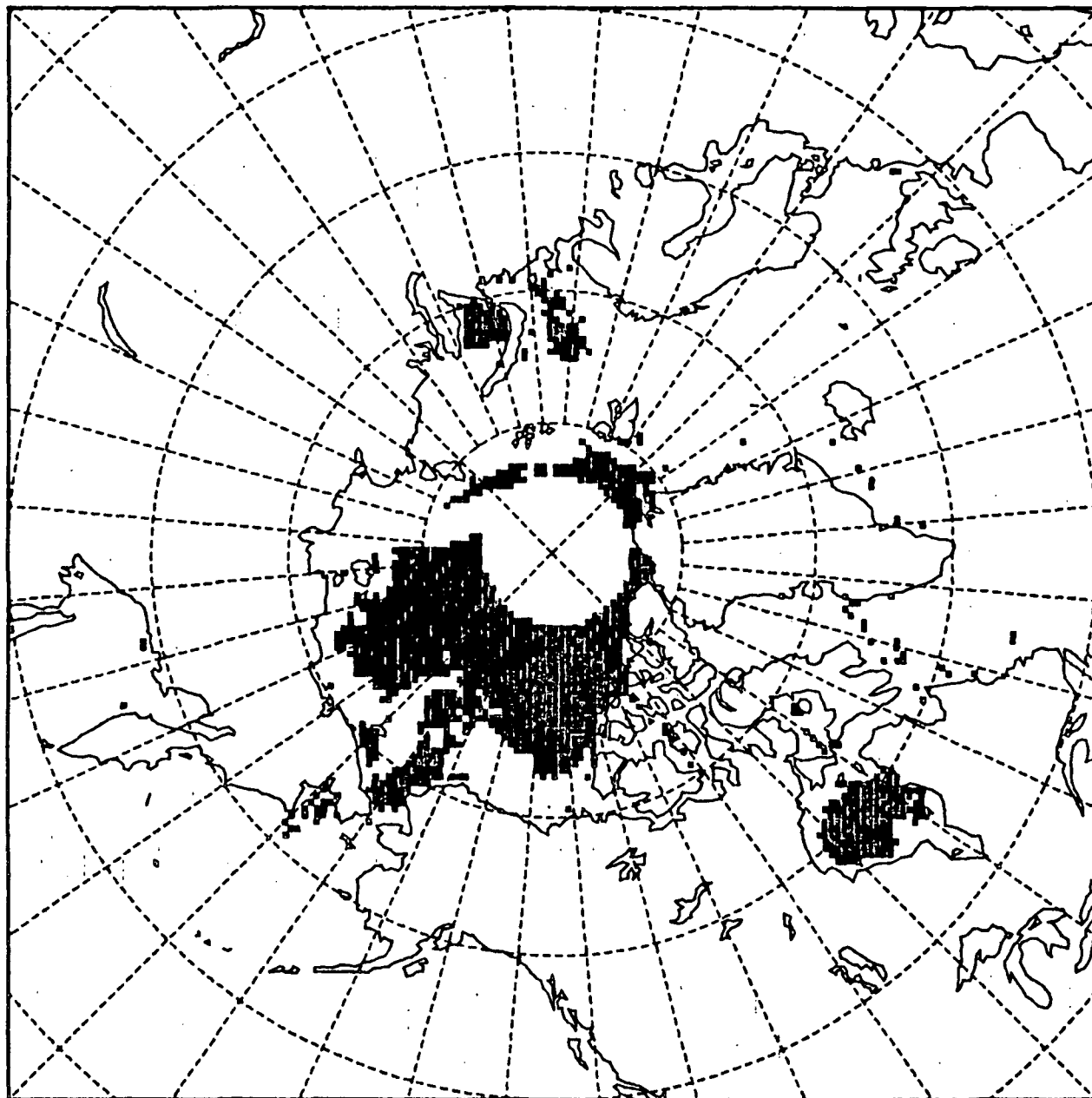
16 MAY 78 – 19 MAY 79

60 KM GRID

NIMBUS 7 SMMR
SEA ICE
CONCENTRATION

EAST GREENLAND SEA

26 APR 79

70 N

80 N

10 E

0 E

60 KM GRID

ORBITS 2541 - 2552
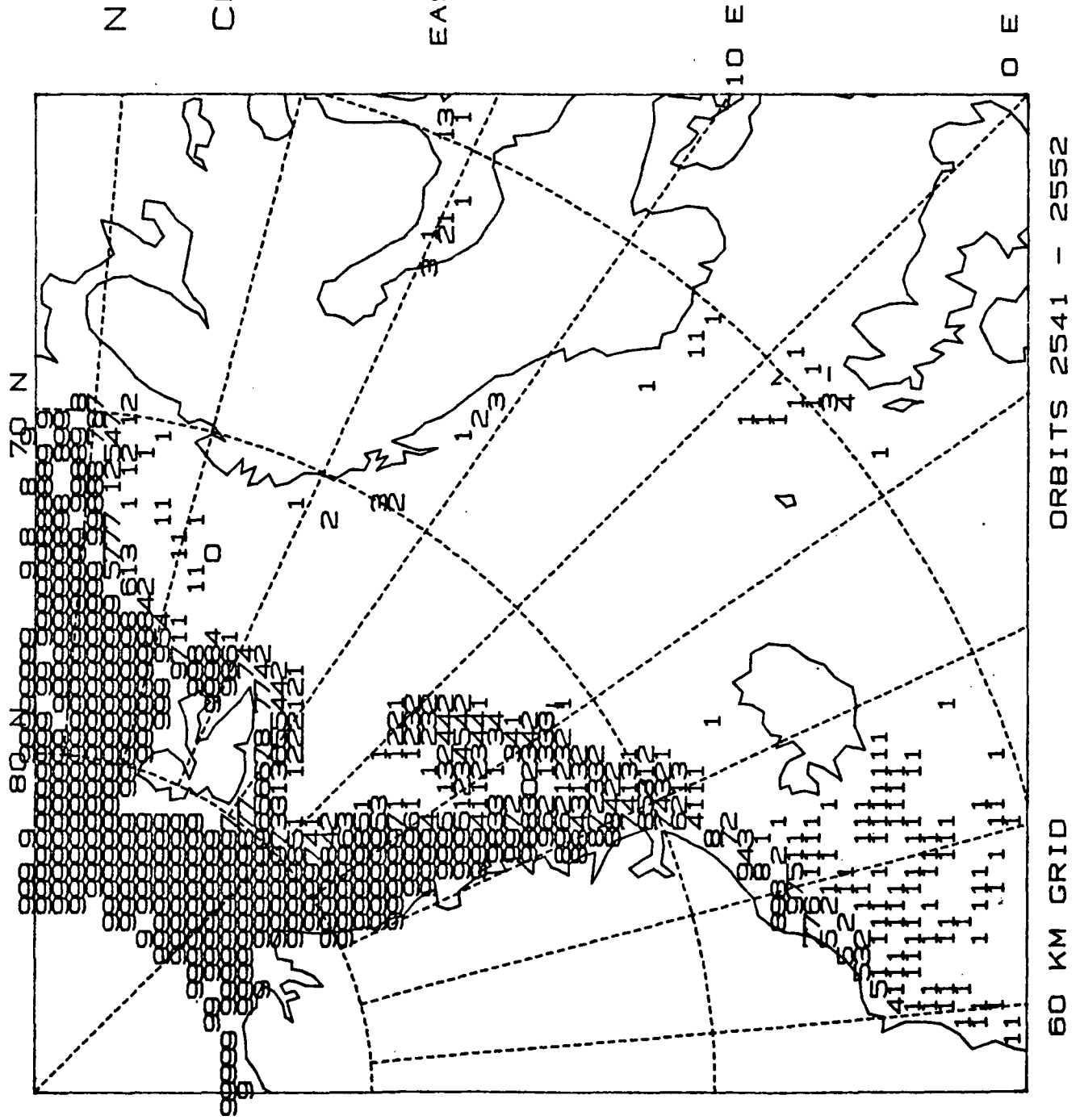
Appendix C.

Conference Papers Supported in Whole or in Part under NAGW – 363

Anderson, M.R. and R.G. Crane, 1984: Atmosphere-Ice Interaction Studies using

    Nimbus-7 SMMR, presented at the AMS Conference on Satellite

    Meteorology/Remote Sensing and Applications, Tampa, Florida, June 25-29

    1984.

Anderson, M.R., R.G. Crane and R.G. Barry, 1984: Characteristics of Arctic Ocean

    Ice Determined from SMMR Data for 1979: Case studies in the seasonal sea

    ice zone, presented at the COSPAR Symposium on Space Observations for

    Climate Studies, Graz, Austria, June 25-29, 1984.

Appendix D.

Publications Supported in Whole or in Part under NAGW - 363

D.8

ARCTIC ATMOSPHERE - ICE INTERACTION STUDIES USING NIMBUS-7 SMMR

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1. INTRODUCTION

The interaction between sea ice and atmospheric dynamics and thermodynamics has been the subject of numerous recent empirical and modeling studies (cf. reviews by the Polar Group, 1980; Crane, 1981). Most analyses, however, have been on seasonal, interannual, or longer time scales. Short term variations in ice extent have been noted and synoptic scale ice-atmosphere interactions have been examined, for example, by Ackley and Keliher (1976), Carleton (1981) and Overland and Pease (1982).

The influence of the atmosphere on the ice is seen primarily in the heat exchange at the surface, and also in the effect of surface winds on ice drift. Very rapid changes in sea ice distribution are possible in the marginal ice zone due to ablation and to ice advection as a response to changes in atmospheric circulation. The present paper describes two such events, one in the Greenland Sea and one in the Sea of Okhotsk, both for April/May 1979.

Analysis of such rapid events have been hampered, in the past, by the lack of accurate data on a suitable time and space scale. Research in this direction has been improved following the availability of satellite borne microwave radiometers. The major advantage of passive microwave sensors is the ability to "see" through cloud and the polar night. Data from the single channel Nimbus-5 Electrically Scanning Microwave Radiometer (ESMR) have been analysed in the context of ice-atmosphere interactions by Cavalieri and Parkinson (1981) for the Southern Ocean and by Crane et al. (1982) and Crane (1983) for regions of the Arctic.

The ESMR data provide a valuable resource for sea ice research. In the absence of supplementary data on ice temperatures and ice type or concentration, however, studies based on the single channel ESMR data are limited by their inability to resolve quantitatively these separate surface parameters. An attempt to alleviate this problem has been made with the launch of the Scanning Multichannel Microwave Radiometer (SMMR) on board Nimbus-7. Using SMMR data, ice concentration, the multi-year ice fraction, and the physical ice temperature have been derived sequentially from the multiple

channel and dual polarization information. These parameters are produced by NASA Goddard Space Flight Center and are currently available for the first year of SMMR operation (November 1978 - October 1979). The derived sea ice concentration data for April and May 1979 are used here in the analysis of ice edge movement and ice concentration changes for the two study periods mentioned above.

2. NIMBUS-7 SMMR SEA ICE PARAMETERS

The Nimbus-7 SMMR records passive microwave radiation, at both horizontal and vertical polarizations, for each of five wavelengths: 6.6GHz (4.6cm); 10.7GHz (2.8cm); 18 GHz(1.7cm); 21GHz (1.4cm); and 37GHz (0.81cm). A method for retrieving ice concentration, multi-year ice fraction and the physical ice temperature has been described by Cavalieri et al. (in press). The procedure defines a polarization ratio, given by:

$$R = (TB_v - TB_h) / (TB_v + TB_h)$$

where TB_v and TB_h are the vertical and horizontal brightness temperatures recorded in a given channel. Use is made of the large polarization difference between open water and sea ice to estimate ice concentration at the 18GHz wavelength (water vapor has little effect on atmospheric attenuation at this wavelength). The use of the polarization ratio enables the derivation of the parameters to be virtually independent of the physical temperature of the surface. An initial value of 50% multi-year ice fraction is used to obtain an approximate sea ice concentration, and an iterative procedure is then used to arrive at final values of ice concentration and multi-year ice fraction. The physical ice temperature is inferred from the ice concentration and the 6.6GHz vertical brightness temperature, and the multi-year ice fraction is used to obtain the ice concentration at 37GHz.

The ice concentration retrievals at 18GHz correspond to a spatial resolution of approximately 60km, while those at 37GHz correspond to a 30km resolution. The multi-year ice fraction has a 60km resolution and the multi-year ice fraction, since it makes use of the 6.6GHz channel, has a resolution of 150km.

3. THE GREENLAND SEA

Ice extent in the Greenland Sea is largely determined by ice export from the Arctic Basin via the East Greenland Current (EGC), and by the formation of new ice within the current. This ice forms a continuous flow from north to south along the east Greenland coast. The distribution of the ice, however, is also influenced by an oceanic gyre (the Jan Mayen Gyre) north of Iceland. In winter this frequently causes an extension eastwards of a lobe of ice, referred to as "Odden", (Vinje, 1980) in the southern limb of the gyre.

An examination of the U.S. Navy–NOAA Joint Ice Center (JIC) sea ice analyses shows this feature to be particularly well developed in March/April 1979. The JIC analyses routinely use SMMR in the determination of the ice edge location. Ice concentration within the pack is based primarily on visual analysis of higher resolution visible and infrared imagery from the NOAA and Defense Meteorological Satellite Program (DMSP) series of satellites. Ice analyses from these sensors, however, are restricted by cloud conditions.

During April, under conditions of weak surface winds, Odden was separated from the main

(a)

(b)

(c)

(d)
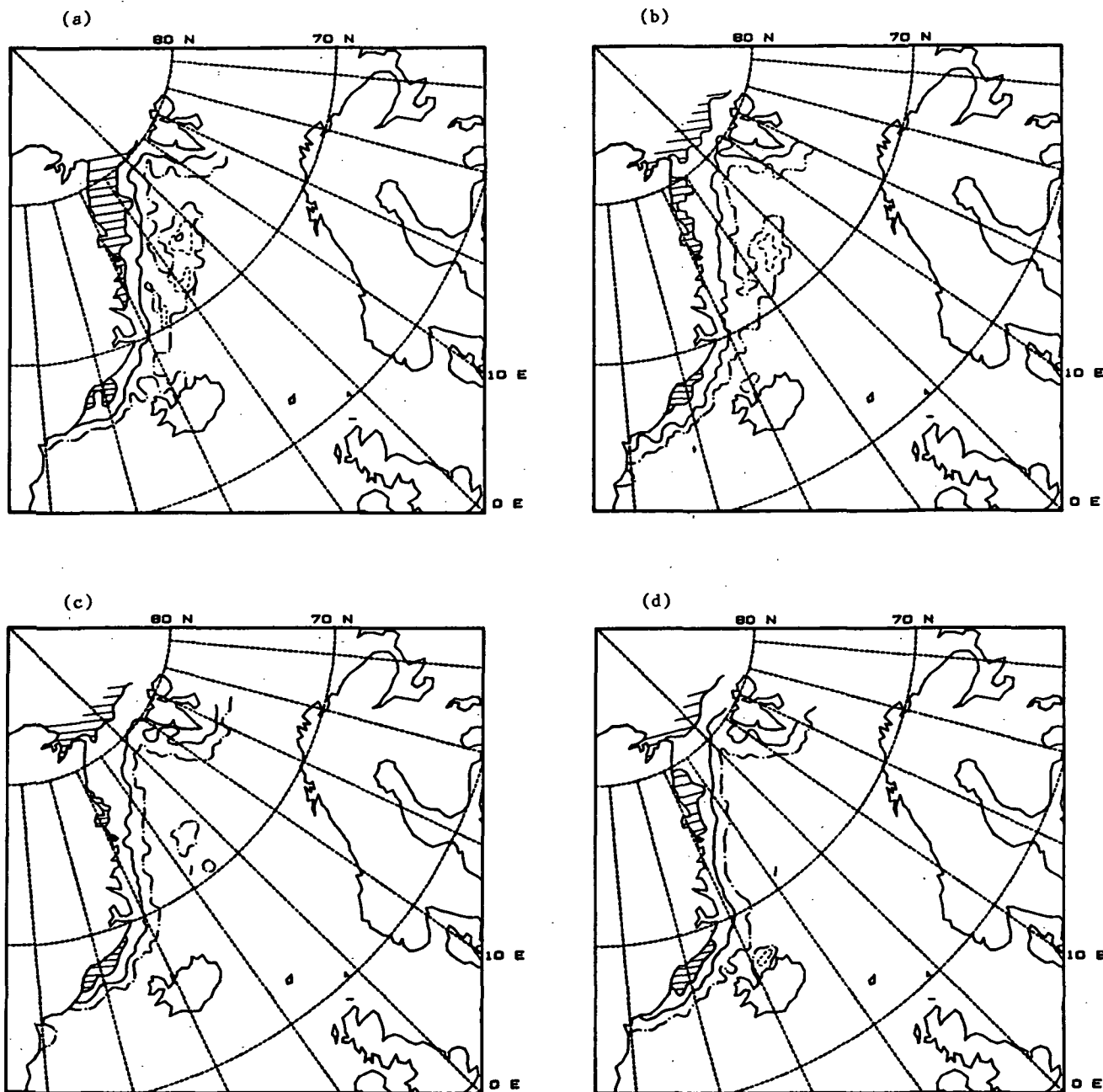
Figure 1.   Nimbus-7 SMMR sea ice concentrations in the Greenland Sea for: a) 28 April; b) 30 April; c) 2 May; d) 4 May 1979. —·—— = ice edge; ———— = 30%; and ———— = 50% ice concentration. The hatched areas are greater than 90% concentration.

coastal flow by a strip of open water 80-150km wide. The weekly JIC ice charts show that the lobe disappears sometime between the 29 April and 8 May. The daily DMSP visual and IR imagery shows extensive cloud cover over the region for much of the period, limiting its usefulness for ice analysis. A detailed analysis of the SMMR data, however, indicates that the change took place between the first and the fourth of May (Figure 1).

The ice band is present in the SMMR data through the end of April (Figure 1a;b). The next data day on the 2 May (SMMR operates only on

(a)

(b)

Figure 2. Sea level pressure patterns for:
a) 26 April and b) 2 May 1979.

alternate days due to power limitations), showed a rapid decrease in ice extent and concentration (Figure 1c). On 4 May (Figure 1d) the ice had completely disappeared from the region northeast of Iceland. Figure 1d also shows that the ice extent in the EGC decreases between about 71N and 74N, and that there is a slight increase in the Denmark Strait between Greenland and Iceland.

An analysis of the surface pressure charts shows weak high pressure in the region in late April; a representative surface pressure map is shown in Figure 2a. During this period the ice distribution is determined by the oceanic gyre (Vinje, 1980), with the weak atmospheric circulation having very little influence.

A low pressure system develops in the region towards the end of April. The system intensifies and moves southeast during the first four days of May (eg. Figure 2b). The change in wind speed results in the rapid break-up of Odden. The strong cyclonic flow may also account for the apparent ice convergence in the Denmark Strait (cf. Aagaard, 1972).

4. SEA OF OKHOTSK

The seasonal sea ice distribution in the Sea of Okhotsk has been described by Parkinson and Gratz (1983), using Nimbus-5 ESMR data. Their results suggest that there is a rapid retreat of ice from the Kamchatka coast in mid-March, with the ice remaining along the northern and western coasts through April/May.

A similar situation to the Greenland case can be seen in early May in the Sea of Okhotsk. The JIC ice analyses show a change occurring from one weekly analysis to the next. Again, analysis of the sea ice extent is hindered by cloud cover in the visual and IR DMSP imagery, while variations in ice cover can be clearly seen in the SMMR data.

From late April to early May, ice extent and concentration remains fairly stable (ice extent between 4-7 May is given in Figure 3a). SMMR data for 8-10 May shows little change in ice extent, but a substantial decrease in ice concentration in the northern part of the region (Figure 3b). Figure 3c for 12-14 May shows a rapid break-up of the ice pack with large changes in both ice concentration and areal extent. The atmospheric circulation again changes from one of weak anticyclonic flow (Figure 4a) to a more intense cyclonic flow (Figure 4b)

Parkinson and Gratz (1983) found that the typical ablation pattern in April/May consisted of ice lingering along the western coasts with in situ break-up as a result of polynya formation. A similar situation is observed in the SMMR data, except that in this case, the change in atmospheric circulation results in the rapid disintegration of the ice cover. It would appear that the break-up is accelerated by warm air advection. The resulting ice distribution (Figure 3c) is probably related to the Okhotsk gyre north east of Sakhalin Island.

5. DISCUSSION

The temporal and spatial resolution available with the satellite - borne microwave radiometers provide a valuable source of information for sea ice analysis and monitoring in the marginal ice
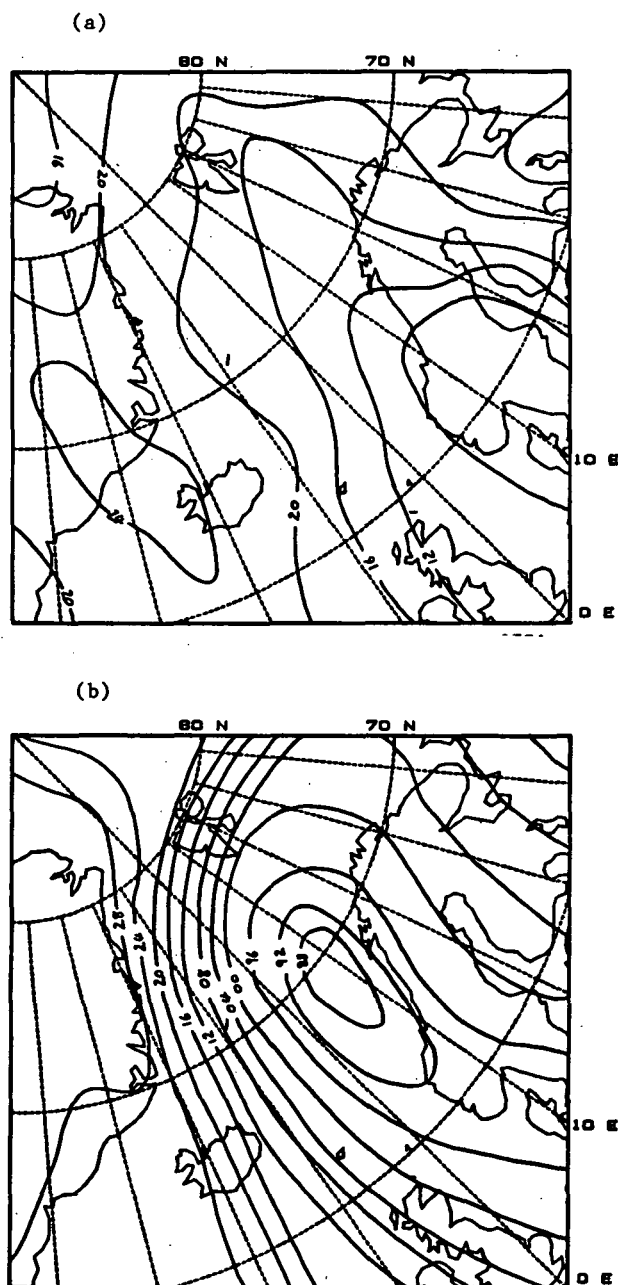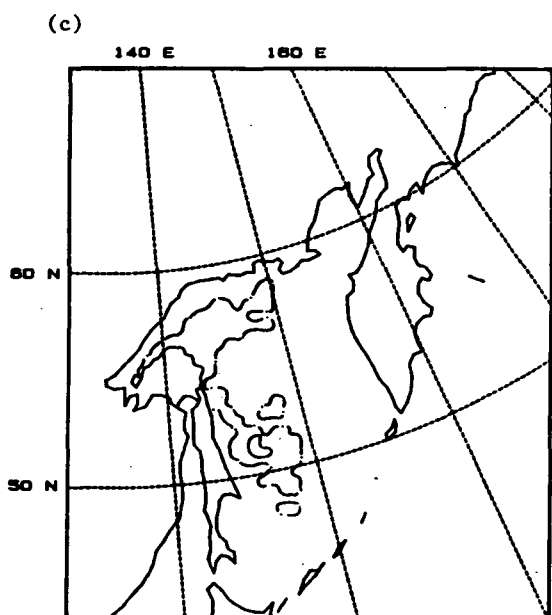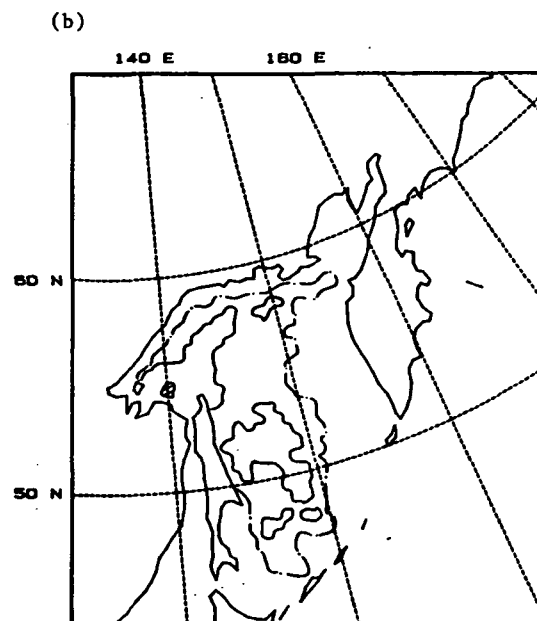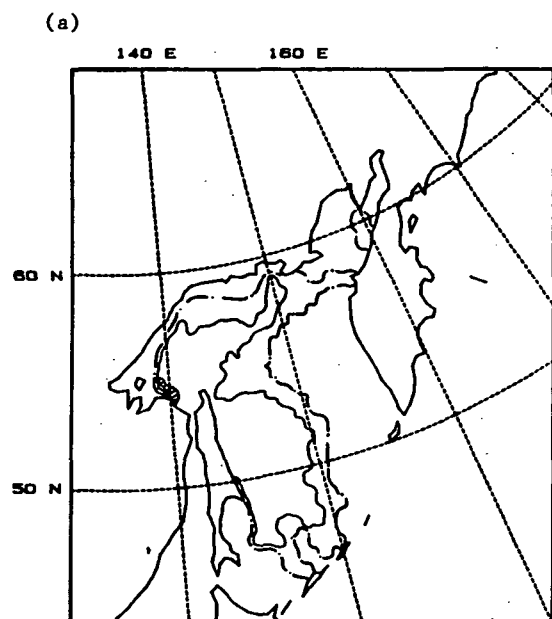
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(a)

(b)

(c)

Figure 3. Nimbus-7 SMMR sea ice concentrations
in the Sea of Okhotsk for: a) 4-7 May;
b) 8-10 May; c) 12-14 May 1979. ——·—— = ice
edge; ———— = 50% ice concentration, and the
hatched areas are greater than 90%.

zone. Using the SMMR data, rapid changes in ice
extent and concentration have been observed in
association with changes in synoptic atmospheric
circulation.

Case studies and analyses of sample data
indicate that ice concentration estimates may be
accurate to within 10% (Cavalieri et al., in
press). Limitations in ice concentration
retrievals exist in the marginal ice zone due to
ocean surface roughness and precipitation, both
of which tend to return erroneous ice
concentration values over areas of open water.
Work is still in progress to improve the sea ice
algorithms.

In the case studies described above, orbital
characteristics provide sufficient overlap to
permit data every two days in the Greenland Sea.
Three-day averages are used for the Sea of
Okhotsk due to the limited orbital
coverage at this latitude. In 1985/6 a
multi-channel microwave radiometer will be
included on a DMSP platform. The sensor will
operate at four frequencies: 19.3, 22.2, 37.0
and 85.5 GHz. Vertical and horizontal
polarizations will be provided for all
frequencies except the 22.2 GHz, which will only
have vertical polarization. The lower frequency
channels will have a scene station resolution of

(a)

140 E   160 E

60 N

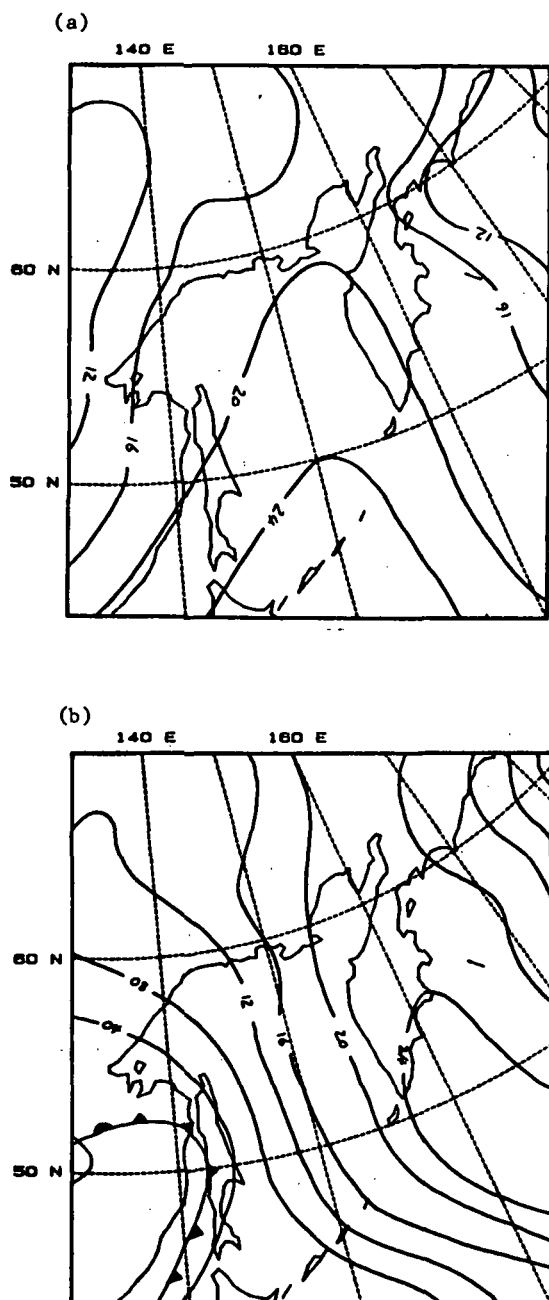50 N

(b)

140 E   160 E

60 N

50 N

Figure 4. Sea level pressure patterns for:
  a) 4 May and b) 9 May 1979.

25km, and the 85.5 GHz channel will have a resolution of 12.5km.

The satellite orbital characteristics will permit improved temporal coverage compared to SMMR, with repeat global coverage every 24 hours. In the polar regions, complete coverage will be possible every 12 hours due to orbital overlap. The first launch is scheduled for late 1985, with subsequent launches in 1986 and 1987. This sensor will, therefore, provide the primary sea ice data source for the remainder of the decade and permit more extensive studies of the type reported here.

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Characteristics of Arctic Ocean Ice Determined From SMMR Data

For 1979:   Case Studies in the Seasonal Sea Ice Zone

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and

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University of Colorado, Boulder

ABSTRACT

Sea ice data derived from the Scanning Multichannel Microwave Radiometer are examined for sections of the Arctic Ocean during early summer 1979. The temporary appearance of anomalously high multiyear ice fractions in the seasonal ice zones of the Kara and Barents Seas is a result of surface melt phenomena and the relative responses of the different channels to these effects. Such anomalies have the potential for providing additional information on surface characteristics during the melt.

INTRODUCTION

The use of the all-weather capability of satellite passive microwave data for mapping sea ice extent and, in certain locations, ice concentration has become a well-established tool for polar ice research. Following the successful demonstration of this approach with the single channel Electrically Scanning Microwave Radiometer (ESMR) data on Nimbus-5 /1, 2, 3, 4/, attention has now turned to the augmented capabilities provided by data from the Nimbus-7 Scanning Multichannel Microwave Radiometer (SMMR). The sea ice products derived from these data by the NASA Goddard Space Flight Center, utilizing the SMMR Team Algorithm /5/, are ice concentration, multiyear (MYI) fraction and ice surface temperature. Polar subsets of these sea ice data have been produced at the World Data Center-A for Glaciology.

In the course of preparing sequential maps of the SMMR-derived ice concentration and MYI fraction from the data for 1979, several potential difficulties for users of the data were noticed. Among these problems are spurious ice concentrations of up to 80-90 percent in adjacent ocean areas, resulting from the effect of waves on the ocean surface and rainfall.

These cause uncertainty in defining the ice edge location and lobes of low to moderate ice concentration in the marginal zone. A case where such an ice lobe is confirmed using ancillary data analysis is described by Anderson and Crane /6/. Future SMMR data will have the ice edge more clearly demarcated through use of a spectral gradient ratio filter and areas of spurious ice concentration removed /7/. This will not be the case for the first three years of SMMR data produced (including the FGGE year) unless the products are reprocessed.

It was also noticed that areas of apparently high MYI fraction suddenly appear and then disappear in sections of the seasonal sea ice zone where the ice type is known to be primarily first year ice. The contemporaneous changes in total ice concentration are generally in the opposite direction, but relatively modest in amount. The algorithm calculates the fraction of the total ice cover that is multiyear ice. For the present paper, actual MYI concentrations have been derived which confirm that the changes described above are not simply due to variations in the first year ice cover. This paper examines the conditions associated with these MYI anomalies. It is recognized that the current algorithms generally cannot discriminate between first and multiyear ice during summer conditions owing to the effects of surface melt, as a result of temperature-induced variations in snow/ice emissivity near the melting point /5/. Nevertheless, the present study shows that the anomalies in MYI fractions have the potential for providing additional information on surface characteristics at this season in the zone of seasonal sea ice.

DATA

The SMMR is a five frequency, dual-polarized, passive microwave radiometer operating on Nimbus-7 in a near-polar orbit /8/. The principal data discussed here are obtained from the 37 GHz (0.81 cm), 18 GHz (1.7 cm) and 6.6 GHz (4.6 cm) channels, which have spatial resolutions of approximately 30 km, 60 km, and 150 km respectively. The large polarization difference between open water and sea ice is used to estimate ice concentration from the ratio between the 18 GHz vertical and horizontal brightness temperatures. The gradient between the 37 GHz and 18 GHz brightness temperatures also gives some indication of ice type. For sea ice this gradient is positive, with much larger differences being observed for multiyear compared with first year ice. For open ocean the gradient is negative. Use of

these brightness temperature ratios enables the derivation to be virtually independent of the physical temperature of the surface. The 6.6 GHz vertical polarization brightness temperature is used, in conjunction with the calculated ice concentration to estimate the ice surface temperature. At the present time, these geophysical parameters have been produced for 1979 and 1980 in two tape formats. The PARM-SS tapes contain sea ice, ice sheet and snow parameter data in an orbital format. The MAP-SS tapes have the orbital PARM-SS data mapped to 30, 60 or 156 km polar grids /9/.

ANALYSIS AND DISCUSSION

The observed characteristics of these areas of spurious MYI fraction are described and possible explanations are then considered. The spatial pattern of temporal changes in MYI fraction in the Eurasian sector of the Arctic for May 1979 is illustrated in Figure 1. Time sequences of sea ice concentration and MYI fraction in the southern Kara Sea and Barents Sea for 1 March-15 August are shown in Figure 2. These are computed for 180 x 180 km areas centered on 71.1°N, 61.0°E (Kara Sea) and 72.8°N, 45.0°E (Barents Sea). At the beginning of May, both areas show a sudden rise in the MYI fraction from near zero to about 80 percent. This occurs as the SMMR-derived total ice concentration is declining by some 20 percent. The MYI fraction decreases by the third week in May to 10 percent in the Barents Sea and 40 percent in the Kara Sea. In the latter area it rebounds to 80 percent in early June, but only to 30 percent in the Barents Sea. The total ice concentration in both areas shows small fluctuations during this period.

We examine first the large-scale cloud cover as identified on visible Defense Meteorological Satellite Program (DMSP) imagery for the period late April through early May. During early May when the MYI fraction reaches a maximum, the area of the Barents-Kara Sea is relatively cloud free and there is little likelihood that any atmospheric effects due to liquid water or rainfall have contaminated the microwave data. When clouds are present, they are evidently thin because surface features remain visible through them.

It would appear, therefore, that the fluctuations of MYI fraction are a result of surface effects on emissivity. Inspection of the DMSP imagery supplemented by the Norwegian ice charts indicates that ice conditions in the two areas are somewhat different. There is essentially 10/10 ice cover in the Kara Sea compared with about 8/10 broken and fractured ice
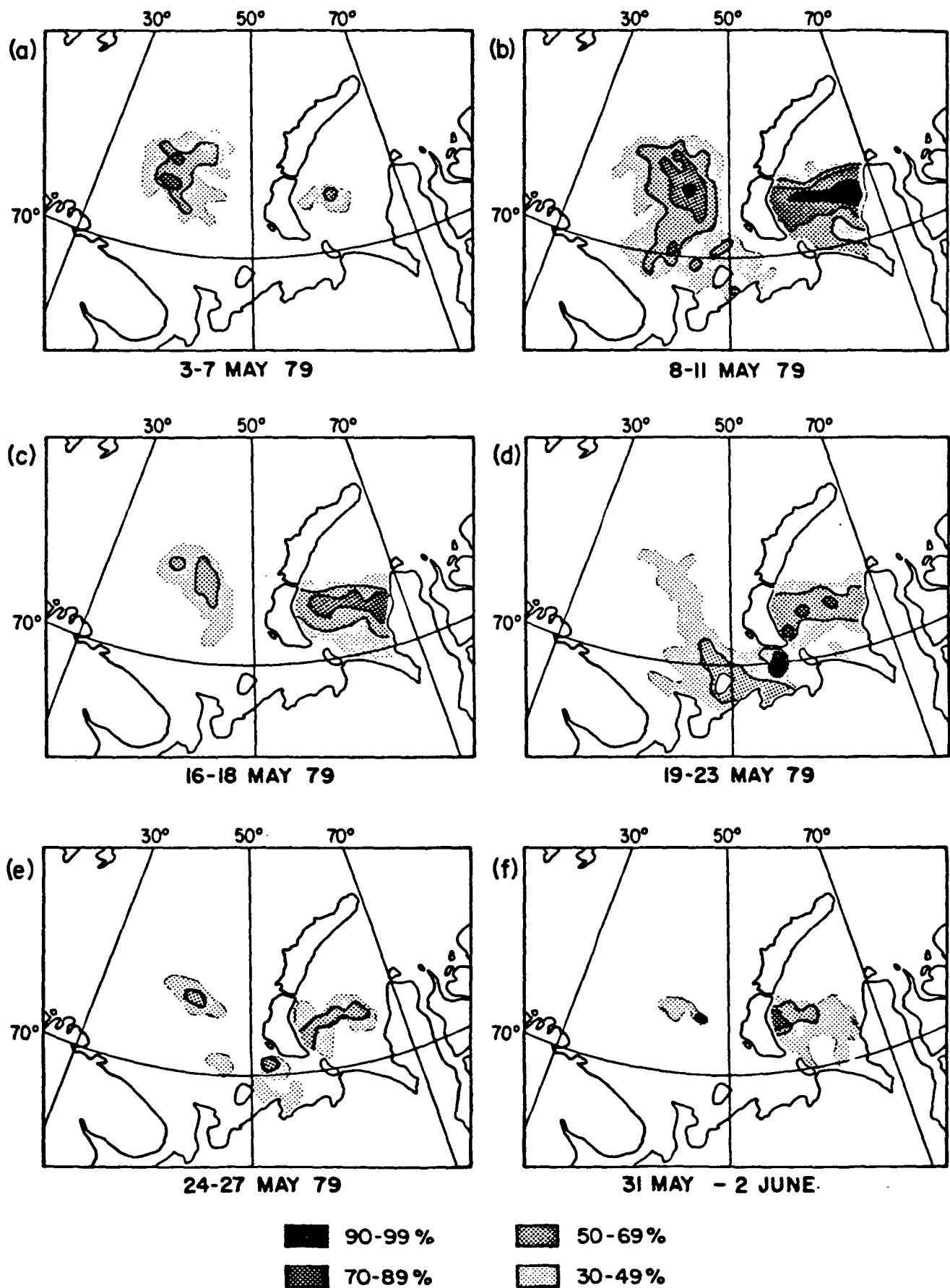
-4-

Fig. 1. Four-day average multiyear ice fractions for the Kara/Barents Sea, May 1979.
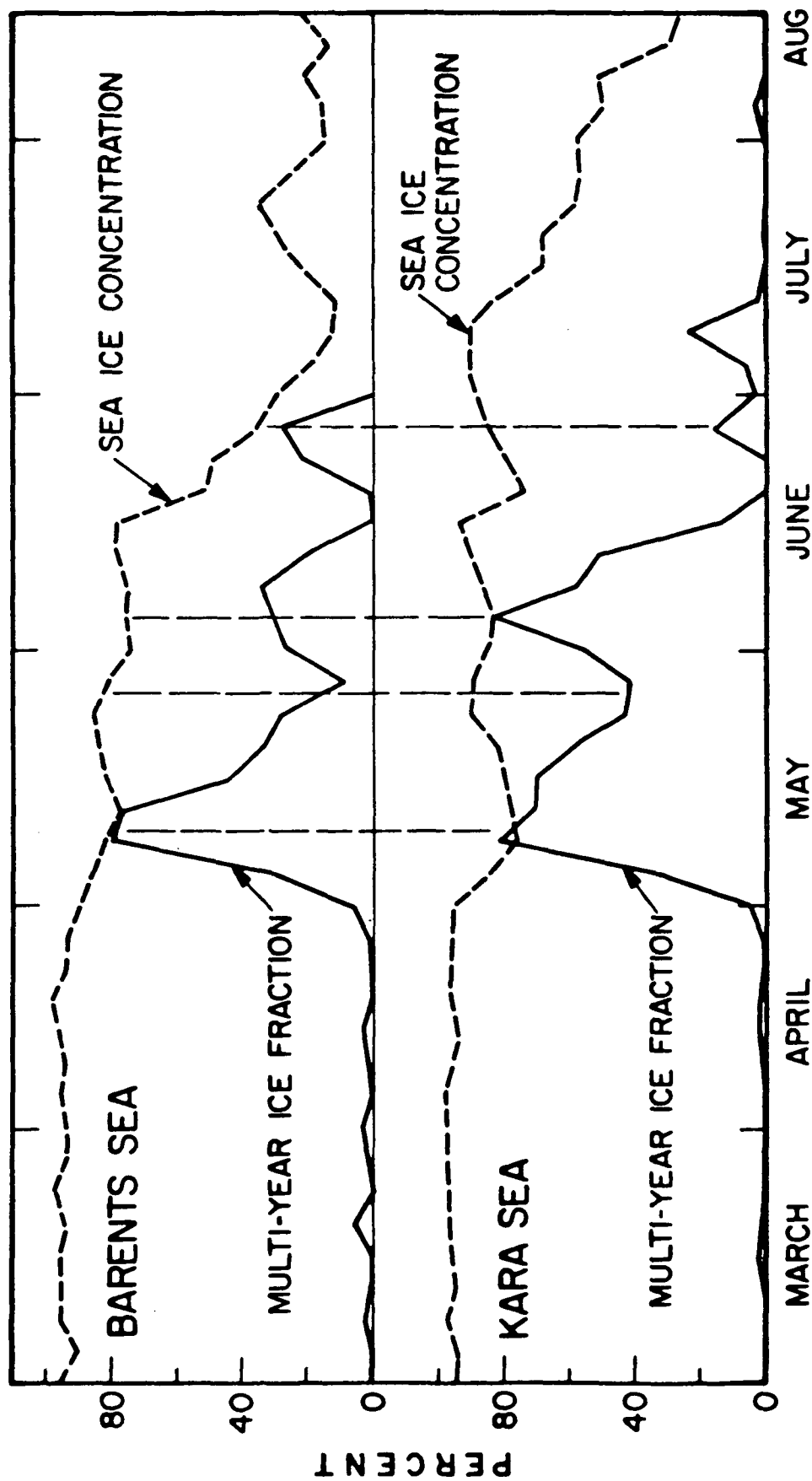
Fig. 2. Time sequences of sea ice concentration and multiyear ice fraction for 180 x 180 km areas centered on 71.1° N, 61.0° E (Barents Sea) and 82.8° N, 45.0° E (Kara Sea), March–August 1979.

in the Barents Sea, where it is subject to a fair degree of motion. In late April/May low pressure in the Norwegian Sea results in southeasterly off-shore flow in the area of the Barents Sea, with reduced ice concentration in its southeastern parts and the formation of coastal leads and polynyi around the western coast of Novaya Zemlaya. Between the 4th and 6th of May, low pressure develops over the Taymyr Peninsula to the north-east of Novaya Zemlya resulting in on-shore flow in the southern Barents Sea, where ice concentrations increase and the coastal polynyi are reduced. The ice cover remains land-locked in the Kara Sea during this time and appears to show little change. It is worth noting that the SMMR derived total ice concentrations (Figure 2) show a reduction in the Kara Sea as well as the Barents Sea. This is not apparent on the DMSP imagery, although there could be sub-resolution leads.

In view of their apparently differing surface conditions, the similarity of the changes in MYI fraction in the two areas during this interval is somewhat surprising. Accordingly, we examine the time changes in the brightness temperatures in the 18 and 37 GHz channels at vertical polarization. Plots of brightness temperatures are shown for the Kara and Barents Sea areas in Figure 3. The MYI fractions are our calculations using the brightness temperatures averaged for 2 data days in each 4 day interval and differ slightly from those given by the PARM-SS data (Figure 2). This is probably due to different binning techniques and averaging methods. The 37 GHz vertical polarization brightness temperatures for May respond similarly in the southern Kara and Barents seas with a 40K decrease in the Barents Sea and a 25K decrease in the southern Kara Sea. However, the fluctuations in the 18 GHz brightness temperatures are dissimilar. In the northern Kara Sea area, where there is no significant MYI fraction, the 37 and 18 GHz channels show similar values, whereas in the two areas where the algorithm indicates the presence of multiyear ice, the 18 GHz brightness temperature is generally much greater than that at 37 GHz. The decreasing brightness temperatures in early May show that the emissivity fluctuations are not due simply to the onset of snow melt. For melting snow, the presence of free water is known to cause initial increases in brightness temperature. For example, Rango et al. /10/ cite changes of up to 35K in the 37 GHz channel for a deep snow pack undergoing melting on the Great Plains. This
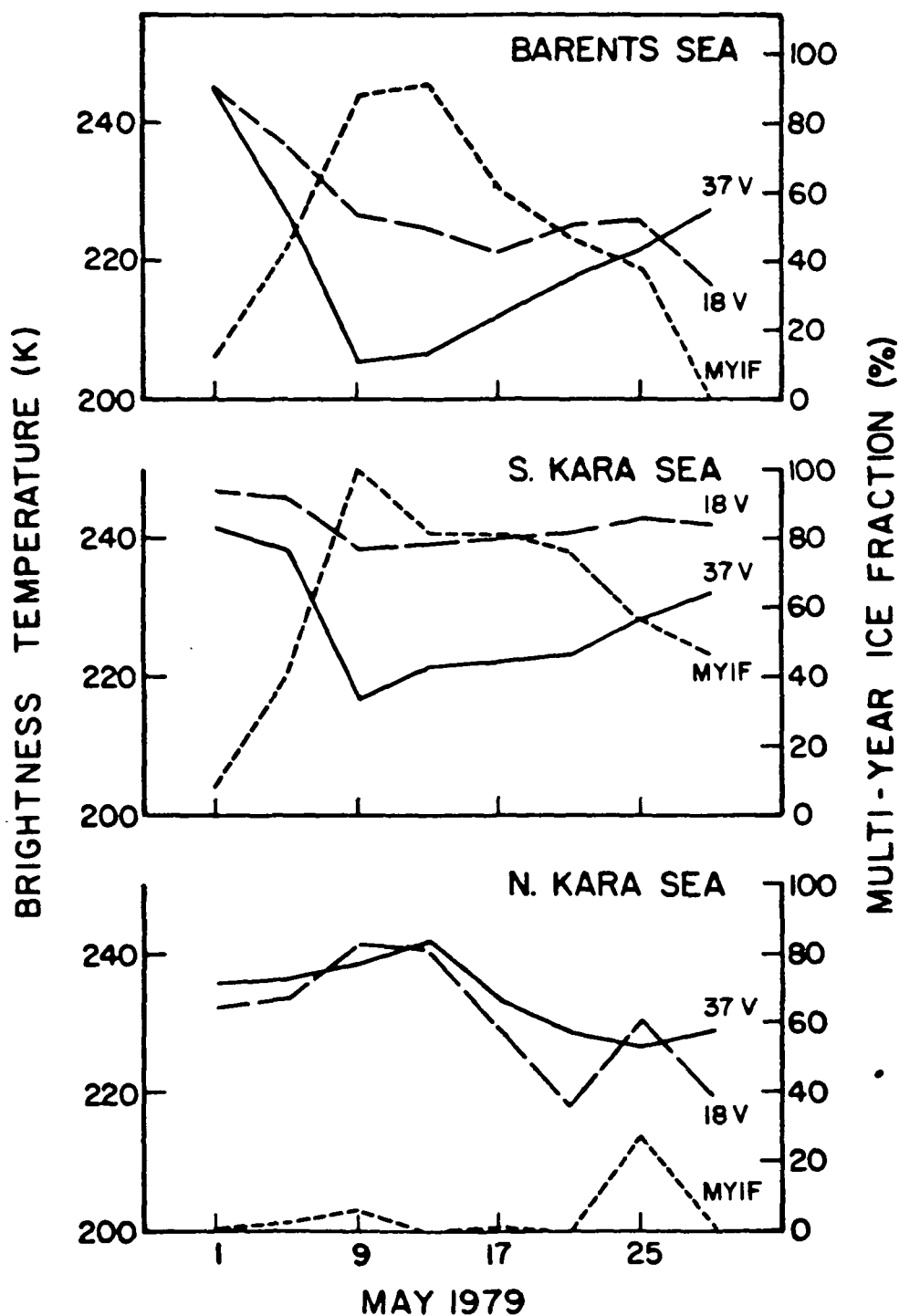
Fig. 3. 18 and 37 GHz vertical brightness temperatures and computed multiyear ice
fractions for the two anomalous multiyear ice fraction regions (Barents
Sea and Southern Kara Sea), and for a region of little multiyear ice
(Northern Kara Sea).

contrasts with the large brightness temperature decrease observed with the same frequency in the two sea ice areas (Figure 3).

The decrease in the brightness temperatures observed in the Kara/Barents Sea are probably a result of melt at the snow/ice interface. The penetration depth for saline ice is on the order of the wavelength of the radiation /11/. The greater penetration depth of the 18 GHz (1.7 cm) channel shows that this melt is confined to a thin layer at the ice surface in the Kara Sea, where the 18 GHz brightness temperature shows little variation. In the Barents Sea the larger decrease in the 18 GHz brightness temperature suggests that this melt has penetrated to a greater depth. In this case, there also appears to be a time lag of 8 days between the minimum values observed in the 18 and 37 GHz brightness temperatures, which again could be a function of the time taken for the melt to reach that depth. It is possible that some flooding of the freeboard layer due to the ice movement in the Barents Sea may also contribute to this effect /12/. Station air temperatures reported from Novaya Zemlya are well below freezing for most of this time period. The melt is, therefore, probably due to the absorption of penetrating solar radiation rather than warm air advection.

The SMMR-derived surface ice temperatures in the two areas are plotted in Figures 4 and 5 in relation to the MYI fraction. For the southern Kara Sea the curves show a strong positive correlation and are almost coincident in timing. The 10°C values computed for the Kara Sea in early May and early June are in error since the surface temperature will not rise above about 1°C. In the Barents Sea, in contrast, the surface ice temperatures do not rise above -10°C. These temperatures are too low to allow ice melt which would suggest that, in this case, the algorithm is underestimating the surface ice temperature. This could be because the meltwater results in lower 6.6 GHz vertical brightness temperatures than would normally be the case given the ice concentration, which would then result in lower derived physical temperatures. Again, the implication is that the estimation of ice temperature is complicated under conditions of surface melt.

CONCLUSIONS

Areas of anomalous multiyear ice fraction have been observed in the SMMR derived sea ice parameter data for the Barents and Kara Seas during May 1979. Both areas are regions of predominantly first year ice. Examination of the 18 and 37 GHz vertical brightness
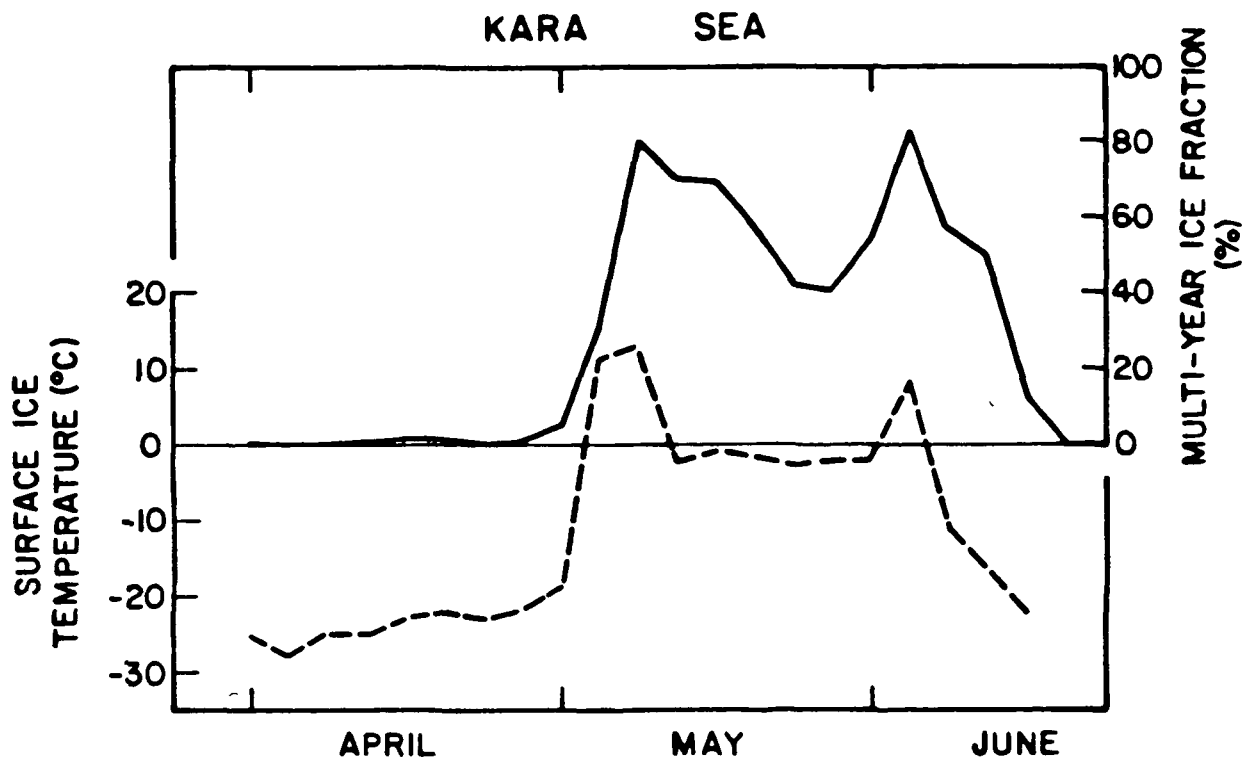
Fig. 4. SMMR derived surface ice temperature and multiyear ice fraction for the Kara Sea, April/May 1979.
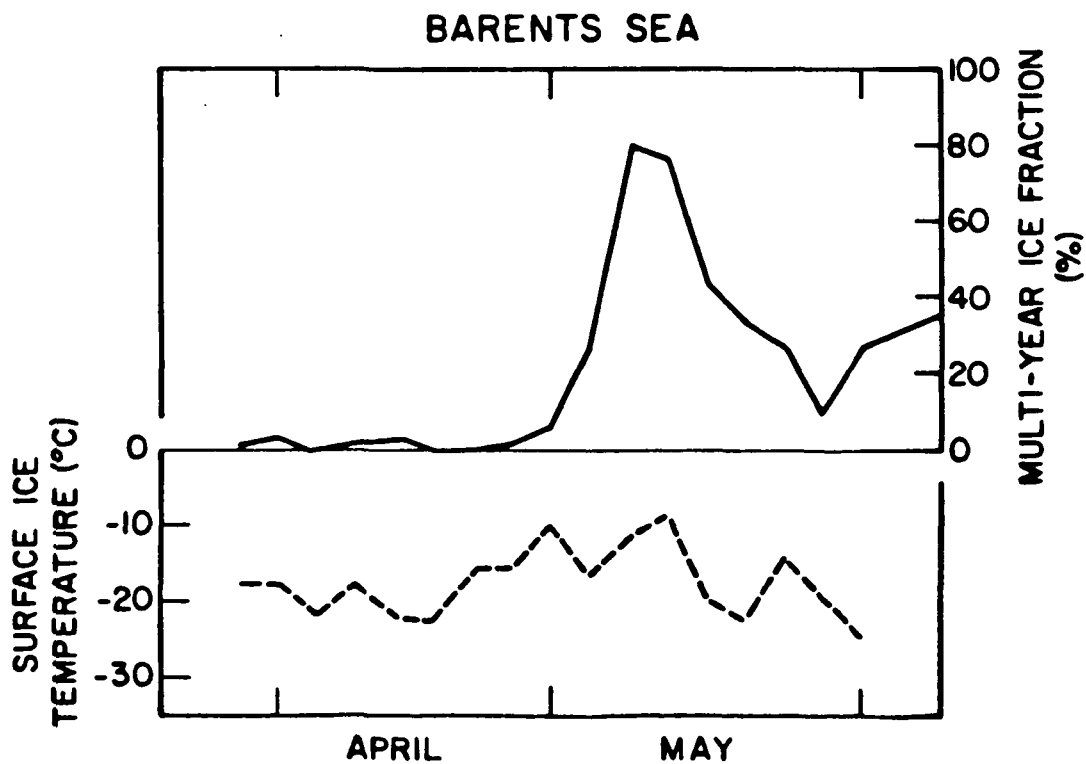

Fig. 5. SMMR derived surface ice temperature and multiyear ice fraction for the Barents Sea, April/May 1979.

temperatures suggest that these anomalous multiyear ice fractions result from ice melt at the snow/ice interface. Predominantly clear skies, and below freezing air temperatures indicate that the melt is probably due to absorption of solar radiation at this interface.

The occurrence of these anomalous multiyear ice fractions can be used to indicate areas and timing of the initial spring melt. However, surface observations of ice conditions during this preliminary melt period are necessary to fully understand the microwave signatures.

ACKNOWLEDGMENTS

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